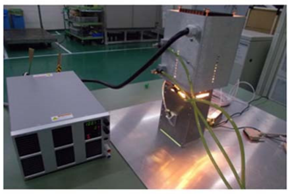
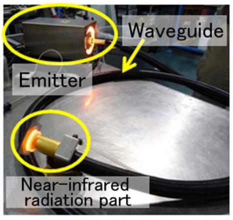
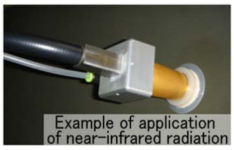
Development of Rapid Adhesion Method for Assembling Plastic Parts Using Near-Infrared







YUICHI YUI[*1] AKIHISA OKUDA[*2]
MASANORI KUBOTA[*3]

The replacement of the conventional mechanical joint using bolts, etc., with an adhesive joint, among methods for assembling parts, has been studied in terms of weight and cost reduction. One of the issues in replacement is the curing time of the adhesive. To address this issue, the principle of the rapid heating method using near-infrared radiation[1, 2] developed by Kubota Research Associates, Inc. was verified. In addition, a simulation tool which allows the estimation of the change of temperature of the adhesive layer by near-infrared heating was developed to facilitate the study of the applicability of the method.

1. Introduction

Among transportation equipment such as aircraft and automobiles, the mechanical joint method using bolts, etc., is most frequently used to join parts, but in using this method, increased part thickness to compensate for the reduced strength due to boring and the weight of the bolts causes an increase in product weight. In addition, the labor cost required for a joint with bolts and the cost of bolts themselves lead to the increase of product prices. One possible measure to address these disadvantages of a mechanical joint is replacement with the adhesive joint method as shown in **Figure 1**. Adhesives for aircraft structures which can be cured at room temperature require 24 hours to generate the handling strength which allows moving on to the next process (for example, assembly of wiring to plastic parts), and an additional one week is required for the development of the fully-cured strength. Such a long curing time worsens the product flow time. Therefore, in order to positively apply an adhesive joint as a joining method, it is absolutely necessary to reduce the curing time of adhesives.

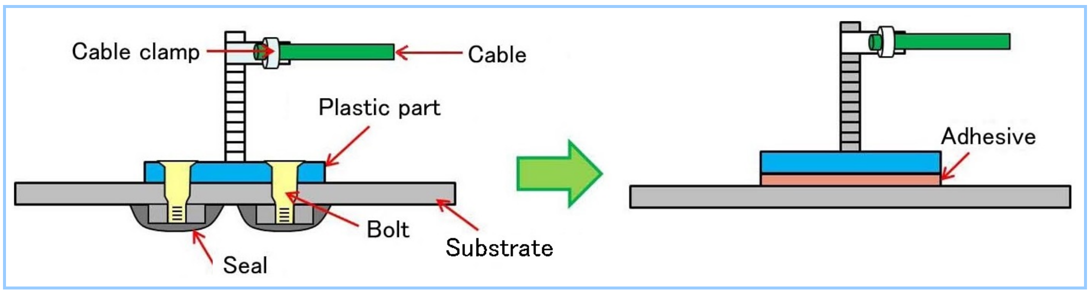


Figure 1 Example of replacement of mechanical joint to adhesive joint

As a measure for reducing the curing time on joints of plastic parts, Mitsubishi Heavy Industries, Ltd. (MHI) focused attention on the rapid adhesive curing method (P-Wave^{TM}/PTIR^{TM}* method) using near-infrared radiation developed by Kubota Research Associates, Inc. and verified its principle. As a result, it was found that the time for the handling strength generation that was conventionally 24 hours could be within 6 minutes. Furthermore, in order to apply this method to

*1 Manufacturing Technology Research Department, Research & Innovation Center
*2 Research Manager, Manufacturing Technology Research Department, Research & Innovation Center
*3 Kubota Research Associates, Inc. CEO MBA

various parts/adhesives, a simulation tool which allows the estimation of the change in temperature of the adhesive layer by near-infrared radiation was developed.

* P-Wave™: Polychromatic Wave
PTIR™: Pseudo-Transmission Infrared Radiation

2. P-Wave™/PTIR™ method

One possible measure for reducing the curing time of adhesives is an increase in the reaction rate of the adhesive by heating. But in hot air heating that is generally used, after plastic parts are heated, the adhesive is heated by heat conduction from the plastic parts, and therefore, many hours are required for the adhesive to reach the target temperature. Even in far-infrared heating, which is used in the rapid heating of polymer resins such as adhesives, much of the energy is absorbed in the plastic parts, and the adhesive is heated by heat conduction from the plastic parts in the same way as hot air heating, which is not effective.

The P-Wave™/PTIR™ method is a method where near-infrared radiation which is difficult for plastic parts to absorb are used to make the energy reach the adhesive efficiently, and PTIR™ particles which absorb near-infrared radiation dispersed in the adhesive and emit far-infrared radiation are used to directly and selectively heat the adhesive rapidly (**Figure 2**).

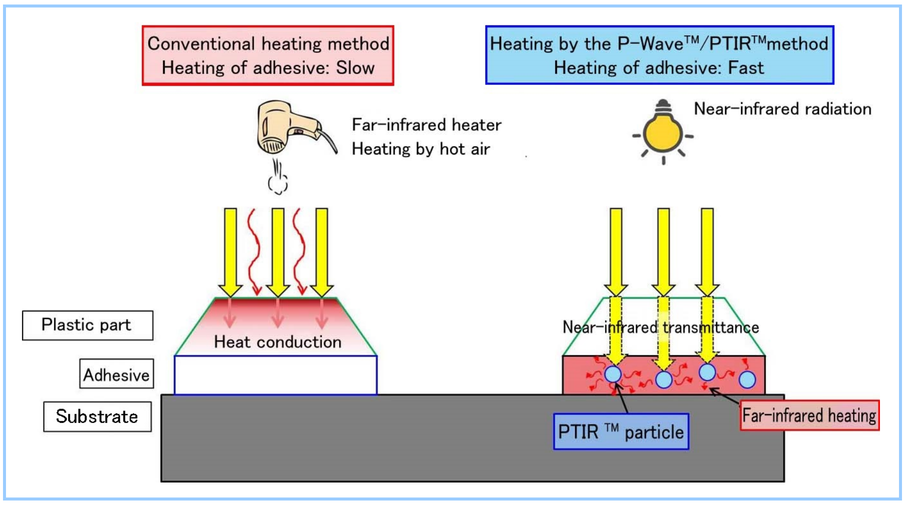


Figure 2 Comparison of the conventional heating method and the P-Wave™/PTIR™ method

3. Verification of principle of P-Wave™/PTIR™ method

In order to verify the effectiveness of the P-Wave™/PTIR™ method, using plastic parts for aircraft and structural adhesive for aircraft (epoxy adhesive), the data on the time for the joints to attain the strength (handling strength) that allows moving on to the next process and the fully-cured strength that can be generated when the adhesive is rapidly heated were obtained.

In order to verify the time for generating the handling strength, a test specimen using the plastic part for aircraft as shown in **Figure 3** was prepared, and after near-infrared radiation was irradiated for a predetermined time, the withstand load of the part was measured. The test conditions are as shown in **Table 1**. The results indicated that if the joint is heated to about 120°C at which the thermal effect on the base material and the plastic part is small, a sufficient handling strength can be obtained by 6 minutes of near-infrared radiation (**Figure 4**).

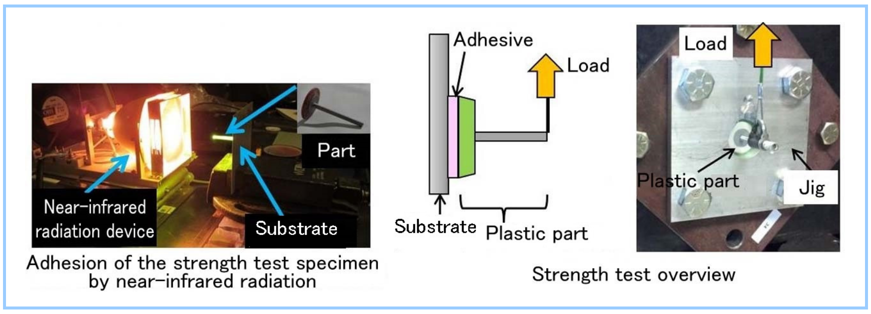


Figure 3 Overview of the handling strength test

Table 1 Conditions of the verification test for the time for the generation of the handling strength

ID	Type of adhesive	Adhesion area	PTIR mixing ratio	Maximum temperature	Duration of near-infrared radiation
1	Epoxy-based, room temperature curing-type paste adhesive	Approximately 791 mm^2	0 wt%	25°C	0 minutes*
2			0.04 wt%	80°C	15 minutes
3				120°C	6 minutes

*Cured at room temperature for 24 hours

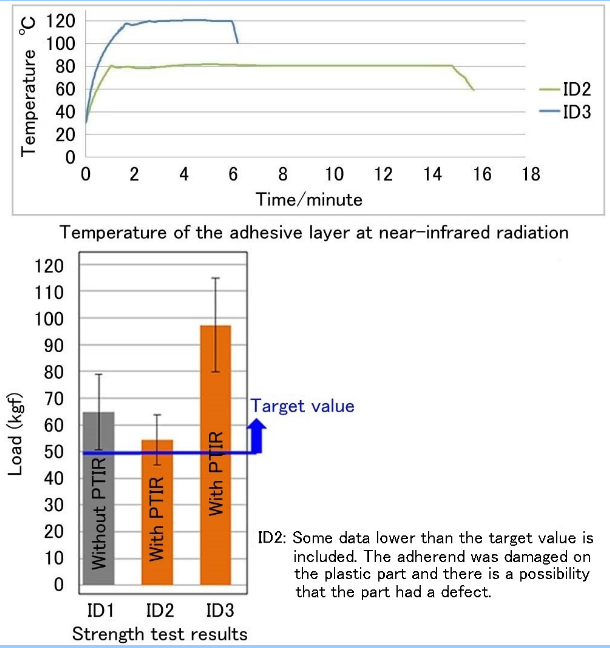


Figure 4 Verification test results of the handling strength generation time

Furthermore, to check the effect of the P-Wave^{TM}/PTIR^{TM} method on the fully-cured adhesive strength, near-infrared radiation was irradiated for 15 minutes (until the temperature reaches 120°C at maximum), and then the adhesive strength (shearing strength) after the adhesive was completely cured at room temperature was obtained.[3] The results showed that a sufficient adhesive strength of 20 MPa was obtained (**Figure 5**).

Test conditions

ID	Adhesive	PTIR mixing ratio	Maximum temperature	Duration of near-infrared radiation	Fully-cured condition
1	Epoxy-based, room temperature curing-type paste adhesive	0 wt%	25 °C	0 minutes*	7 days at room temperature
2		0.04 wt%	120 °C	15 minutes	7 days at room temperature

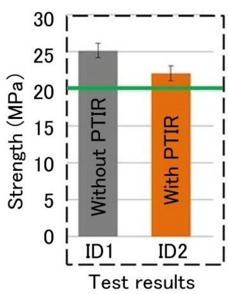


Figure 5 Test Conditions and results of the fully-cured strength test

4. Development of simulation tool for adhesive temperature at near-infrared heating

By the principle verification test shown in Section 3, the effectiveness of the P-Wave^{TM}/PTIR^{TM} method was proved. On the other hand, the temperature increasing property of adhesive by near-infrared radiation depends on the near-infrared transmittance of the plastic part and the heating efficiency of the adhesive by far-infrared radiation. Therefore, the kind of material of the adhesive and the part and the board thickness are the key parameters. As such, to determine the applicability of the P-Wave^{TM}/PTIR^{TM} method to each product, it is important to immediately understand the heating properties when the method is applied to each product. We prepared a model in which the near-infrared energy passes through a plastic part and far-infrared radiation, which is absorbed in/wavelength-converted by PTIR particles dispersed in the adhesive, heat the adhesive (**Figure 6**) and developed the simulation tool (accuracy <6°C) (**Figure 7**) which allows the determination of the behaviors of the adhesive by temperature when it is irradiated by the specified near-infrared energy. This tool allows the calculation of the change in temperature of the adhesive layer using, as input data, the near-infrared radiation intensity, the near-infrared transmittance of the plastic part and the temperature increasing property in near-infrared radiation when only adhesive is targeted. For base materials, such as CFRP, which have a low heat conductivity, the effect of the heat radiation on the base material can be ignored. For base materials, such as aluminum, which have a high heat conductivity, a correction value must be added to the temperature increasing property of the adhesive. In the verification of the calculation precision of this tool, the error was +6°C in the adhesion of the GFRP part to the CFRP substrate (top in Figure 7) and the error was +3°C in the adhesion of the GFRP part to the aluminum substrate (bottom in Figure 7). The results show that this tool has a sufficient calculation precision and enables the estimation of the time for the generation of the handling strength when P-Wave^{TM}/PTIR^{TM} is applied.

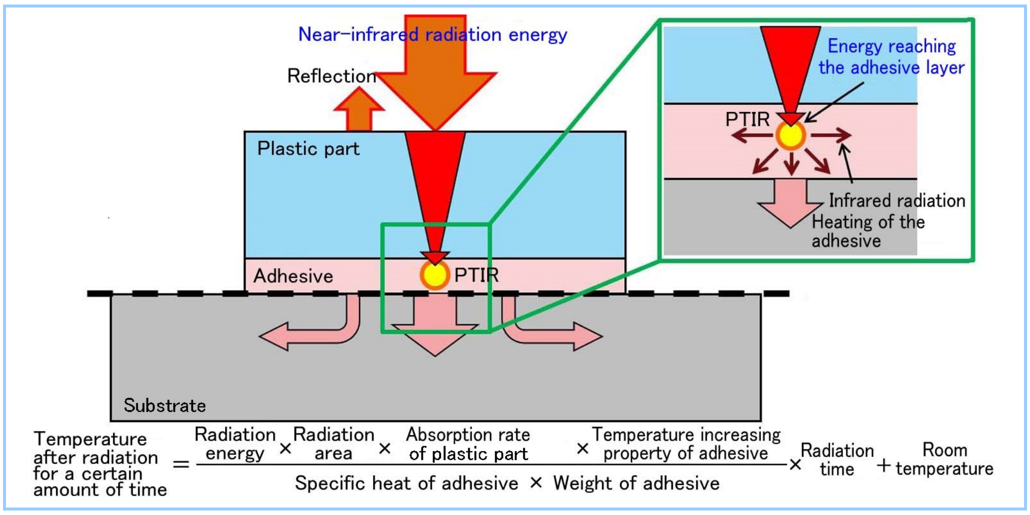


Figure 6 Adhesive layer heating model by near-infrared radiation

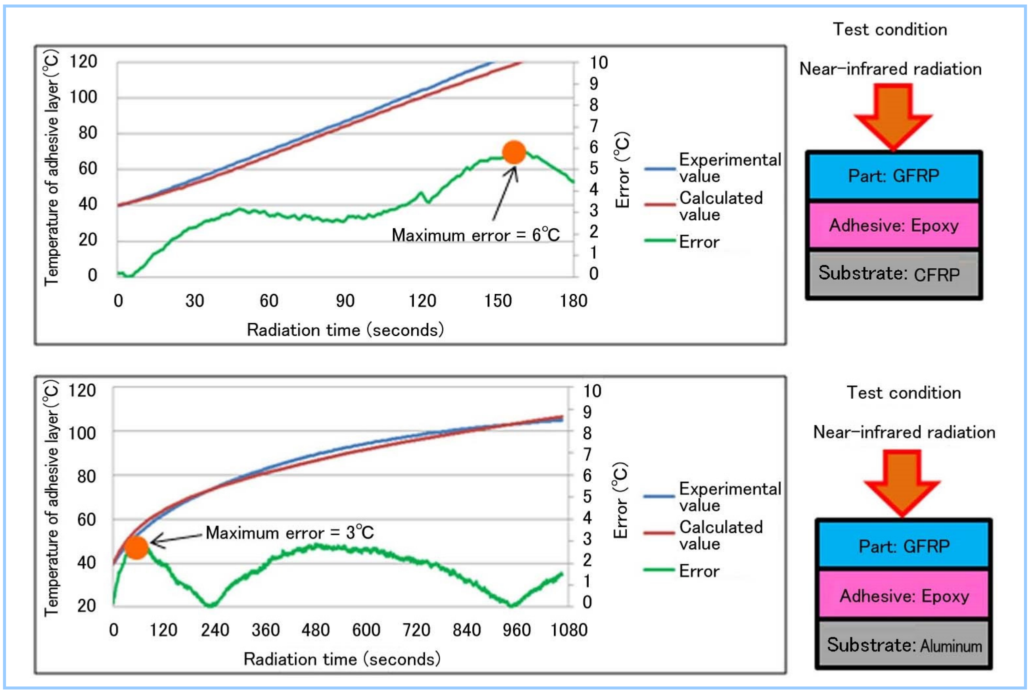


Figure 7 Results of verification of appropriateness of the model by comparison of the experimental values and the calculated values

5. Conclusions

(1) Verification of principle of P-Wave^{TM}/PTIR^{TM} method

- The handling strength generation time for structural adhesive for aircraft can be reduced from 24 hours to 6 minutes.
- A reduction in adhesive strength by the use of this method was not observed.

(2) The adhesive temperature simulation tool was developed for promoting the application of this method to products.

References

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